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A review on the pattern of electricity generation and emission in Malaysia from 1976 to 2008

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ABSTRACT

Like many other countries, most of the power plants in Malaysia are using fossil fuel for electricity generation. In the past decade, thermal power plants generated about 89.3% of electricity and about 10.7% was generated by renewable sources such as hydropower. This study was conducted to chronicle 33 years of Malaysian electricity generation industry. The capacity of power generation installed and electricity generation from the years 1976 to 2008 has been gathered along with the total pollutant emissions and emission per unit electricity generation for each type of power plants. These were calculated using emission factors, and the pattern of electricity generation and emission production has been presented. The results show that using renewable energy and increasing the contribution of the combined cycle as a best type of thermal power plants and use more natural gas is recommended to reduce emission.

Contents

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1. Introduction

1.1. Energy supply and demand of Malaysia

Malaysian's main energy sources are crude oil, petroleum products, natural gas, coal and hydroelectric plants. Recently, biomass has seen limited use as an alternative energy source [1–3]. This is in part due to the supply of coal and coke increasing while there has been a sharp decrease in oil and petroleum products [3]. The sufficiency, security, reliability and cost-effectiveness of energy supplies in this country is coordinated by the Economic Planning Unit (EPU) and also coordinating the implementation of future power generation projects through a bidding process and a pilot plant on waste-to-energy. Certain projects pertaining to this field is discussed in Refs. [4–8]. Meanwhile the ministry of plantation industries and commodities is developing biofuel [9–13]. Programs related to the provision of reliable and cost-effective supply of energy and renewable energy in Malaysia is presented by Refs. [3,8,14–19].

According to the final energy demand in 2005, the transportation sector was the largest consumer of energy at 40.5 percent of total final commercial energy demand. The share of other sectors is 38.6 percent for industrial and 13.1 percent for residential and commercial respectively [3].

Nomenclature

CV	calorific value (kcal/m^3)
EF	emission factor in power plant (kg/M m^3)
EG	electricity generation from power plant (GWh)
EM	power plant emission (ton)
EP	emission per unit electricity generation (kg/GWh)
EX	exchange electricity with neighbouring countries (GWh)
FC	power plant fuel consumption (M m^3)
FE	share of fuel emission (%)
k, C	constant values
NC	power plant nominal capacity (MW)
NP	share of nominal capacity (%)
P	population
PC	per capita electricity consumption (kWh)
PE	share of electricity generation (%)
PF	share of thermal energy (%)
PN	per capita nominal capacity (W)

Subscripts

f	fuel type consumed in power plant
i	in the year i

Superscripts

n	power plant type
p	emission type
t	thermal power plants

1.2. Electricity generation in Malaysia

The electrical energy demand in Malaysia has increased tremendously in the past 33 years and the energy conservation policy of Malaysia has improved along these lines [20]. The country has extensively implemented energy conservation in order to reduce consumption growth rate. Some of the energy conservation programs in the country are deeply discussed by Refs. [21–35].

Conventional thermal, combined cycle, gas turbine, diesel, hydro, mini hydro and biomass are among the electricity power plants in Malaysia. The country recently decided to utilize coal as the main fuel source for power generation partly in an effort to reduce our dependence on oil and gas. In lieu of these 6420 MW (Megawatts) of new generation capacity was installed [3].

1.3. Non-renewable power plants

Despite of the best efforts of the Malaysian government, most of the power plants in this country are using non-renewable sources such as coal, natural gas, diesel and fuel oil. Some examples of these power plants are steam turbine, combined cycle, gas turbine and diesel engine. Table 1 shows fuel types consumption in all types of Malaysian thermal power plants [36–50].

1.4. Steam turbine power plants

Steam turbine power plant uses high pressure steam to generate electricity. At present 32% of total electricity generation and 31% of total nominal capacity is produced by steam power plants. Efficiency of these power plants in Malaysia is 35% [50].

1.5. Gas turbine power plants

To generate electricity, natural gas can be used in Brayton cycle. Although the initial cost of these power plants is lower than steam turbines, their thermal efficiency is around 28.8%, which is much lower than combined cycle and steam turbine. Currently 3650 MW of nominal capacity and 17,245 GWh of electricity generation in Malaysia are produced by gas turbine power plants [50].

1.6. Combined cycle

In a gas turbine power plant, a high portion of energy is wasted through the expulsion of the exhaust gases; although, it is possible to transfer this energy to a Rankine cycle for electricity generation. Power plants that follow this method are called combined cycle plants. The thermal efficiency of combined cycles in Malaysia

Table 1
Fuel types consumption in all types of Malaysian thermal power plants.

Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine
Coal	x	–	–	–
Natural gas	x	x	x	–
Fuel oil	x	–	–	–
Diesel	–	x	–	x

(x), fuel is consumed in power plant and (–), fuel is not consumed in power plant.

Table 2
Nominal capacity (MW) for various types of Malaysian power plant from 1976 to 2008.

Year	Conventional thermal (Coal)	Conventional thermal (oil/gas)	Gas turbine	Combined cycle	Diesel engine	Hydro-power	Mini hydro	Biomass	Total
1976	0.0	850.0	0.0	0.0	66.9	264.2	0.0	0.0	1181.1
1977	0.0	970.0	0.0	0.0	77.4	264.2	0.0	0.0	1312.6
1978	0.0	970.0	100.0	0.0	94.7	351.2	0.0	0.0	1516.9
1979	0.0	970.0	100.0	0.0	107.1	613.4	0.0	0.0	1791.5
1980	0.0	1210.0	100.0	0.0	117.9	613.4	0.0	0.0	2041.3
1981	0.0	1330.0	100.0	0.0	126.6	613.4	0.0	0.0	2170.1
1982	0.0	1560.0	100.0	0.0	125.6	613.4	0.0	0.0	2399.0
1983	0.0	1612.0	100.0	0.0	139.4	726.4	0.0	0.0	2578.7
1984	0.0	1612.0	260.0	0.0	187.9	846.5	0.0	0.0	2906.4
1985	0.0	1570.0	260.0	600.0	204.5	1146.7	0.0	0.0	3781.2
1986	0.0	2090.0	280.0	900.0	190.3	1250.1	0.0	0.0	4710.4
1987	0.0	1930.0	280.0	900.0	168.7	1250.9	0.0	0.0	4530.5
1988	300.0	1930.0	280.0	900.0	168.8	1251.3	0.0	0.0	4830.1
1989	600.0	1930.0	280.0	900.0	169.0	1252.6	0.0	0.0	5132.5
1990	164.2	2085.0	486.2	1100.0	151.2	1398.0	5.0	0.0	5390.6
1991	190.2	2198.0	632.0	2010.0	166.3	1486.0	8.0	0.0	6691.5
1992	245.0	2431.0	892.0	2221.0	166.3	1573.0	10.0	0.0	7538.3
1993	300.0	2764.0	1112.0	2341.0	168.0	1628.0	15.0	0.0	8328.0
1994	442.0	2423.0	1532.0	2871.0	173.0	1698.0	18.0	0.0	9157.0
1995	632.1	2200.0	1832.0	3210.0	184.0	1743.0	20.0	0.0	9821.1
1996	732.1	2109.0	2213.0	3656.0	210.0	1797.9	23.0	0.0	10,741.0
1997	626.0	2051.0	2785.0	4012.0	236.0	1832.3	26.0	0.0	11,568.3
1998	587.0	1842.0	2884.0	4411.0	265.0	1937.0	29.0	0.0	11,955.0
1999	630.0	1553.0	3312.0	4832.0	273.0	1989.9	31.3	0.0	12,621.2
2000	700.0	1670.0	3456.9	5056.0	295.3	2059.1	33.3	0.0	13,271.6
2001	1700.0	1726.0	3572.9	5345.0	350.7	2078.0	40.5	0.0	14,813.1
2002	1700.0	1560.0	4521.2	5355.0	429.0	2066.1	40.0	0.0	15,671.3
2003	3802.4	1569.3	4526.7	7625.0	503.0	2072.2	40.2	0.0	20,119.7
2004	4692.3	8361.9	1544.0	2807.4	501.3	2105.5	20.1	0.0	20,053.6
2005	3884.4	893.0	4710.4	10336.0	401.8	2053.8	22.3	0.0	22,324.0
2006	4570.6	910.1	3337.0	8858.1	424.7	2083.1	20.2	0.0	20,224.0
2007	5977.3	894.4	3512.2	8878.7	436.3	2094.2	21.8	0.0	21,815.0
2008	5980.7	901.5	3650.0	8861.2	439.8	2088.9	22.0	43.976	21,988.0

Table 3
Electricity generation (GWh) for various types of power plant from 1976 to 2008.

Year	Conventional thermal (Coal)	Conventional thermal (oil/gas)	Gas turbine	Combined cycle	Diesel engine	Hydro-power	Mini hydro	Biomass	Total
1976	0.0	4280.5	0.0	0.0	176.1	717.5	0.0	0.0	5174
1977	0.0	5200.8	0.0	0.0	171.2	680.4	0.0	0.0	6052
1978	0.0	5834.7	0.0	0.0	188.7	752.2	0.0	0.0	6776
1979	0.0	5911.7	251.4	0.0	290.1	901.4	0.0	0.0	7355
1980	0.0	6430.8	303.8	0.0	304.5	1125.6	0.0	0.0	8165
1981	0.0	6797.4	259.4	0.0	300.2	1422.9	0.0	0.0	8780
1982	0.0	7665.2	288.4	0.0	335.1	1216.9	0.0	0.0	9506
1983	0.0	8406.6	354.2	0.0	393.0	1476.3	0.0	0.0	10,630
1984	0.0	8192.6	357.2	0.0	251.9	2812.9	0.0	0.0	11,614
1985	0.0	7433.2	777.4	1097.1	313.1	3003.5	0.0	0.0	12,624
1986	0.0	6832.4	741.3	2062.4	237.9	3640.7	0.0	0.0	13,515
1987	0.0	8104.3	271.6	2503.5	94.9	3671.0	0.0	0.0	14,645
1988	71.8	7309.8	222.3	3865.8	139.3	4586.2	0.0	0.0	16,195
1989	1999.0	7356.1	50.3	3591.6	85.3	5057.1	0.0	0.0	18,139
1990	2300.0	8550.0	51.3	4321.0	102.6	5982.9	20.3	0.0	21,328
1991	3550.0	9450.0	789.0	5432.0	151.6	6321.9	29.9	0.0	25,724
1992	4700.0	10,300.0	1043.0	6178.0	242.7	6951.9	38.9	0.0	29,454
1993	5982.0	11,000.0	1972.0	6689.0	438.9	7332.9	54.2	0.0	33,469
1994	6692.0	12,500.0	3221.0	6777.0	671.5	7539.9	77.9	0.0	37,479
1995	7732.0	13,150.0	4321.0	7222.0	789.3	8013.6	89.3	0.0	41,317
1996	8923.0	14,100.0	5198.0	7730.0	996.9	8111.4	113.8	0.0	45,173
1997	9982.0	15,300.0	6322.0	8612.0	1276.9	8213.3	130.3	0.0	49,837
1998	11,123.0	15,900.0	8431.0	9821.0	1441.5	8332.1	138.9	0.0	55,188
1999	12,451.0	15,600.0	10,132.0	11,221.0	1673.9	8114.1	146.9	0.0	59,339
2000	7809.4	4401.4	12,956.9	40,540.8	1665.7	9755.3	77.0	0.0	70,220
2001	14,764.6	4251.5	14,075.7	40,638.5	1718.4	9678.3	85.1	0.0	69,855
2002	21,700.3	2945.0	12,632.6	31,155.4	1395.0	7362.6	77.5	0.0	77,501
2003	15,409.9	5438.8	18,953.4	32,138.4	1895.3	8487.8	164.8	0.0	82,406
2004	20,938.1	37064.9	6860.6	12,741.1	2049.3	9266.2	89.0	0.0	89,098
2005	17,659.6	3914.2	21,391.8	36,866.7	1729.5	9375.9	91.0	0.0	91,029
2006	21,719.8	4101.6	15,194.5	40,736.3	1771.1	9601.4	93.2	0.0	93,218
2007	28,675.0	3951.7	16,313.3	40,834.0	1823.8	9524.5	101.3	0.0	101,325
2008	29,624.8	4020.5	17,245.9	42,532.8	1904.4	10,051.3	105.8	105.8	105,803

Table 4
Exchange electricity between Malaysia and neighbouring countries (GWh).

Year	Exchange
1976	0.3
1977	0.5
1978	13.3
1979	104
1980	89.1
1981	90.6
1982	67
1983	63.1
1984	69.2
1985	82.5
1986	5.7
1987	2.5
1988	2.8
1989	9.1
1990	58
1991	23.2
1992	23.2
1993	−23.2
1994	−46.4
1995	23.2
1996	11.6
1997	−11.6
1998	−11.6
2000	0.0
2001	0.0
2002	0.0
2003	197.2
2004	522.0
2005	2227.2
2006	2320
2007	2262
2008	475.6

Table 5
Population of Malaysia for selected years between 1975 and 2008.

Year	Population
1976	12,541,571
1977	12,832,604
1978	13,128,942
1979	13,437,840
1980	13,763,441
1981	14,106,332
1982	14,466,535
1983	14,846,704
1984	15,249,772
1985	15,677,187
1986	16,130,844
1987	16,608,660
1988	17,103,098
1989	17,603,827
1990	18,102,000
1991	18,986,000
1992	18,985,000
1993	19,503,000
1994	20,049,000
1995	20,624,000
1996	21,101,000
1997	21,595,000
1998	22,107,000
1999	22,636,000
2000	23,418,000
2001	23,935,000
2002	24,447,000
2003	25,048,000
2004	25,580,000
2005	26,384,000
2006	26,840,000
2007	27,452,000
2008	27,730,000

is 43.8%, making its efficiency higher than other fossil fuel power plants. Today, combined cycles plants in Malaysia have 8861 MW nominal capacity which is equivalent to 40.3% of the total capacity and produce 40.2% of the total electricity generated in the country [50].

1.7. Diesel engine power plants

This kind of power plants is usually used in hospitals as a backup power source and industries that requires a constant, uninterrupted power supply. 2% of nominal capacity and 1.8% of electricity generation in Malaysia are from this type of power plants. The efficiency of diesel power plants is about 32% [50].

1.8. Renewable power plants

The primary energy source such as crude oil, natural gas and other conventional fuels are limited resources formed by geological processes through solar energy accumulation into the earth over millions of years [20]. Renewable energy is generated from renewable resources such as wind, solar, hydro, and geothermal and biomass. Some works related to these renewable energy sources in Malaysia discussed deeply by Refs. [8,51–58]. Non-hydro renewable energy comprises about 5% of global power generating capacity and supplies 3.4% of global electricity production [59].

Malaysia is currently using renewable energy sources such as hydro and mini hydro for electricity production, the abidance of palm oil in Malaysia has also contributed to the use of biomass for electricity production in recent years. Generating electricity from oil mill wastes is discussed in Ref. [6].

1.9. Hydro power plants

From time to time hydro power has been used as a main renewable energy source. Although the initial cost of hydro power plants is higher than fossil fuel plants, their efficiency is generally higher and their life span is longer.

The average annual rainfall of Malaysia is about 2000 mm, which is quite high when compared to the average annual rainfall of the world (750 mm). Malaysia is considered as one of the potential countries for hydro-power plants and 9.5% of nominal capacity and electricity generation in 2008 was from hydro-power plants [50].

1.10. Mini hydro-power plants

This type of power plant is being used to produce electricity in smaller scales such as for houses or small shops in remote area. Due to its smaller scale, it is unnecessary to construct a dam. Currently, mini hydro-power plants have 22 MW nominal capacities which is equivalent to 0.1% of total nominal capacities and produce 106 MWh of total energy generation [50].

1.11. Power plants fuel consumption

The type of fuel that is used for a power plant in a country depends on many factors, such as economic, political and technical parameters. These parameters include cost of the fuels, geographical location of the power plants, availability of the fuel, environmental concerns and medium and long-term policies of the energy sector. Most of Malaysian power generation is from thermal power plants that are using fossil fuels such as coal, natural gas, diesel and petroleum. Coal and natural gas are being used widely for steam turbines, gas turbines and combined cycles are using natural gas. Unlike fuel oil that is allocated to steam turbines, diesel

Table 6
Composition of fuel consumption (M m^3 and ton) in power plants from 1976 to 2008.

Year	Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine	Total
1976	Coal (kton)	–	–	–	–	0
	Natural gas	–	–	–	–	0
	Fuel oil	0.40622347	–	–	–	0.40622347
	Diesel	–	–	–	0.01521211	0.01521211
1977	Coal (kton)	–	–	–	–	0
	Natural gas	–	–	–	–	0
	Fuel oil	0.49355242	–	–	–	0.49355242
	Diesel	–	–	–	0.01479159	0.01479159
1978	Coal (kton)	–	–	–	–	0
	Natural gas	–	–	–	–	0
	Fuel oil	0.55371181	–	–	–	0.55371181
	Diesel	–	–	–	0.01629981	0.01629981
1979	Coal (kton)	–	–	–	–	0
	Natural gas	–	22.9305814	–	–	22.9305814
	Fuel oil	0.56102055	–	–	–	0.56102055
	Diesel	–	–	–	0.02506282	0.02506282
1980	Coal (kton)	–	–	–	–	0
	Natural gas	–	27.7097484	–	–	27.7097484
	Fuel oil	0.61028478	–	–	–	0.61028478
	Diesel	–	–	–	0.02630887	0.02630887
1981	Coal (kton)	–	–	–	–	0
	Natural gas	–	23.6560516	–	–	23.6560516
	Fuel oil	0.64507354	–	–	–	0.64507354
	Diesel	–	–	–	0.02593687	0.02593687
1982	Coal (kton)	–	–	–	–	0
	Natural gas	–	26.29809	–	–	26.29809
	Fuel oil	0.7274299	–	–	–	0.7274299
	Diesel	–	–	–	0.02895513	0.02895513
1983	Coal (kton)	–	–	–	–	0
	Natural gas	–	32.302283	–	–	32.302283
	Fuel oil	0.79778642	–	–	–	0.79778642
	Diesel	–	–	–	0.03395948	0.03395948
1984	Coal (kton)	–	–	–	–	0
	Natural gas	–	32.5777526	–	–	32.5777526
	Fuel oil	0.77747352	–	–	–	0.77747352
	Diesel	–	–	–	0.02176181	0.02176181
1985	Coal (kton)	–	–	–	–	0
	Natural gas	–	54.7076639	116.253786	–	170.96145
	Fuel oil	0.70540654	–	–	–	0.70540654
	Diesel	–	–	–	0.02704851	0.02704851
1986	Coal (kton)	–	–	–	–	0
	Natural gas	–	58.8115649	196.890891	–	255.702456
	Fuel oil	0.64839241	–	–	–	0.64839241
	Diesel	–	–	–	0.02055511	0.02055511
1987	Coal (kton)	–	–	–	–	0
	Natural gas	–	35.432937	215.128546	–	253.092407
	Fuel oil	0.76909845	–	–	–	0.76909845
	Diesel	–	–	–	0.00820218	0.00820218
1988	Coal (kton)	0.01227147	–	–	–	0.01227147
	Natural gas	–	48.4688984	324.368782	–	372.83768
	Fuel oil	0.69370056	–	–	–	0.69370056
	Diesel	–	–	–	0.01203444	0.01203444
1989	Coal (kton)	0.34182909	–	–	–	0.34182909
	Natural gas	–	3.32143995	328.822555	–	332.143995
	Fuel oil	0.69809167	–	–	–	0.69809167
	Diesel	–	–	–	0.0073686	0.0073686
1990	Coal (kton)	0.3933	–	–	–	0.3933
	Natural gas	–	3.9875376	394.766222	–	398.75376
	Fuel oil	0.811395	–	–	–	0.811395
	Diesel	–	–	–	0.00886464	0.00886464
1991	Coal (kton)	0.60705	–	–	–	0.60705
	Natural gas	–	28.36776	538.98744	–	567.3552
	Fuel oil	0.896805	–	–	–	0.896805
	Diesel	–	–	–	0.0130982	0.0130982
1992	Coal (kton)	0.8037	–	–	–	0.8037
	Natural gas	–	59.269968	599.28523	–	658.5552
	Fuel oil	0.97747	–	–	–	0.97747
	Diesel	–	–	–	0.0147916	0.0147916
1993	Coal (kton)	1.022922	–	–	–	1.022922
	Natural gas	–	205.36963	576.61474	–	789.8832
	Fuel oil	1.0439	–	–	–	1.0439
	Diesel	–	–	–	0.037921	0.037921
1994	Coal (kton)	1.144332	–	–	–	1.144332
	Natural gas	–	373.84522	528.85421	–	911.8176
	Fuel oil	1.18625	–	–	–	1.18625
	Diesel	–	–	–	0.0209693	0.0209693

Table 6 (*Continued*)

Year	Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine	Total
1995	Coal (kton)	1.322172	–	–	–	1.322172
	Natural gas	–	393.71788	657.951	–	1052.7216
	Fuel oil	1.247935	–	–	–	1.247935
	Diesel	–	–	–	0.0681955	0.0681955
1996	Coal (kton)	1.525833	–	–	–	1.525833
	Natural gas	–	471.61344	707.42016	–	1179.0336
	Fuel oil	1.33809	–	–	–	1.33809
	Diesel	–	–	–	0.0861322	0.0861322
1997	Coal (kton)	1.706922	–	–	–	1.706922
	Natural gas	–	572.03194	789.94886	–	1361.9808
	Fuel oil	1.45197	–	–	–	1.45197
	Diesel	–	–	–	0.0289551	0.0289551
1998	Coal (kton)	1.902033	–	–	–	1.902033
	Natural gas	–	626.51117	735.46963	–	1361.9808
	Fuel oil	1.50891	–	–	–	1.50891
	Diesel	–	–	–	0.1245456	0.1245456
1999	Coal (kton)	2.129121	–	–	–	2.129121
	Natural gas	–	915.27499	1032.1186	–	1947.3936
	Fuel oil	1.48044	–	–	–	1.48044
	Diesel	–	–	–	0.144625	0.144625
2000	Coal (kton)	2.99	–	–	–	2.99
	Natural gas	6286.38	2793.94	3221.59	–	12,301.91
	Fuel oil	0.60	–	–	–	0.60
	Diesel	–	0.18	–	0.02	0.21
2001	Coal (kton)	3.97	–	–	–	3.97
	Natural gas	6192.20	2796.00	3674.33	–	12,662.53
	Fuel oil	0.75	–	–	–	0.75
	Diesel	–	0.28	–	0.04	0.32
2002	Coal (kton)	5.07	–	–	–	5.07
	Natural gas	6175.32	2844.30	4198.00	–	13,217.62
	Fuel oil	1.39	–	–	–	1.40
	Diesel	–	0.47	–	0.06	0.53
2003	Coal (kton)	8.18	–	–	–	8.18
	Natural gas	3351.72	3047.02	5166.69	–	11,565.43
	Fuel oil	0.39	–	–	–	0.39
	Diesel	–	0.25	–	0.03	0.28
2004	Coal (kton)	10.61	–	–	–	10.61
	Natural gas	8365.17	989.43	1837.53	–	11,192.10
	Fuel oil	0.27	–	–	–	0.27
	Diesel	–	0.23	–	0.07	0.30
2005	Coal (kton)	10.99	–	–	–	10.99
	Natural gas	3503.99	3474.42	5987.83	–	12,966.24
	Fuel oil	0.20	–	–	–	0.20
	Diesel	–	0.41	–	0.03	0.44
2006	Coal (kton)	11.89	–	–	–	11.89
	Natural gas	4133.84	2432.55	6521.62	–	13,088.01
	Fuel oil	0.17	–	–	–	0.17
	Diesel	–	–	–	0.07	0.69
2007	Coal (kton)	14.93	–	–	–	14.94
	Natural gas	4784.99	2392.50	5988.67	–	13,166.16
	Fuel oil	0.20	–	–	–	0.20
	Diesel	–	0.31	–	0.03	0.34
2008	Coal (kton)	16.09	–	–	–	16.09
	Natural gas	5220.16	2675.74	5599.07	–	14,494.98
	Fuel oil	0.17	–	–	–	0.17
	Diesel	–	0.29	–	0.03	0.32

is used in both gas turbines and diesel engines. The types of fuel consumed in Malaysian power plants are presented in Table 1.

1.12. Energy policy in Malaysia

The per capita energy consumption of the majority of the population has increased considerably especially in developed countries [20]. The energy growth in developing countries has been increased rapidly due to major development in several sectors such as residential, commercial, industrial and transport. The electrical energy consumption in Malaysia has increased sharply in the past few years, and modern energy efficient technologies are desperately need to be implemented as national energy policy [20]. The 9th Malaysian plan (2006–2010) emphasizes the security, reliability, and cost effectiveness of energy while focusing on the sustainable development of the energy sector [20]. Some of recommended policies to be implemented in Malaysia are presented by Refs. [60–68].

1.13. Power plants emission

In general, thermal power plants operated using fossil fuels produce huge amounts of air pollutants. The major pollutants that have been considered in this study are carbon monoxide (CO), sulfur dioxide (SO_2), carbon dioxide (CO_2) and nitrogen oxides (NO_x).

To estimate the total emission due to electricity generation in the country, the amount and type of fuel used in all power plants should be identified. Awareness of the amount of emission per unit electricity generation in each type of thermal power plants is necessary to select the best of plant type with regard to air pollutant and assessment of possible emission in the future.

Table 7
Emission factors (kg/KWh) used for estimating emission in power plants.

Fuel type	CO_2	NO_x	SO_2	CO
Coal	1.18	0.0052	0.0139	0.0002
Natural gas	0.53	0.0009	0.0005	0.0005
Fuel oil	0.85	0.0025	0.0164	0.0002
Diesel	0.85	0.0025	0.0164	0.0002

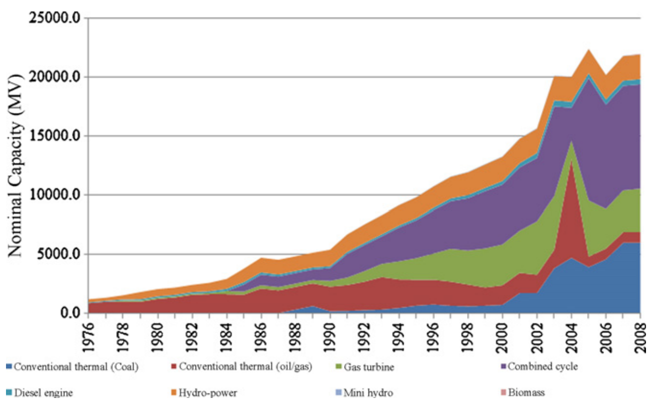

Fig. 1. Nominal capacity (MW) of Malaysian power plants by type of power plant from 1976 to 2008.

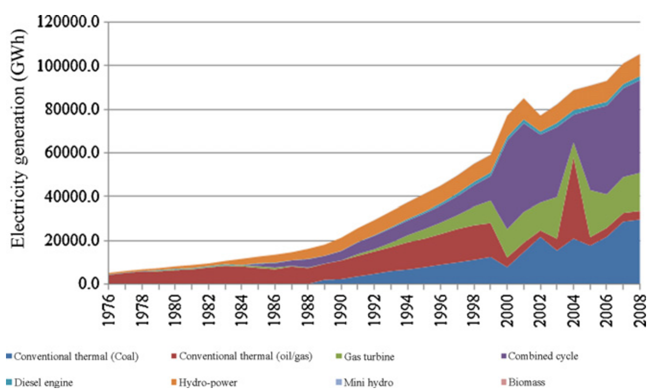

Fig. 2. Electricity generation (GWh)in Malaysian power plants by type of power plant from 1976 to 2008.

2. Survey data

The data used for this study are based on electricity generation, exchanged electricity with neighbouring countries, fossil fuel used and the population of Malaysia from 1976 to 2008. These data collected and extracted from Refs. [36–50] and shown in Tables 2–6. The emission factors for all types of fuel were mostly obtained from Refs. [69–71] and given in Table 7.

3. Methodology

3.1. Method of data estimation

Some data are available but others have to be estimated. There are several methods for estimating data; the one that is widely used is polynomial curve fitting. This method tries to describe the relationship between a variable X as the function of available data and a response Y that seeks to find a smooth curve for the best fit of the data. Mathematically, a polynomial of order k in X can be expressed in the following equation form Refs. [72,73]:

$$Y = C_0 + C_1X + C_2X^2 + \ldots + C_kX^k \tag{1}$$

Table 8
Per capita nominal capacity and per capita electricity consumption in Malaysia.

Year	Per capita nominal capacity (W)	Per capita electricity consumption (kWh)
1976	94	413
1977	102	472
1978	115	515
1979	133	540
1980	148	587
1981	154	616
1982	166	652
1983	174	712
1984	191	757
1985	241	800
1986	292	837
1987	273	882
1988	282	947
1989	292	1030
1990	298	1175
1991	352	1354
1992	397	1550
1993	427	1717
1994	457	1872
1995	476	2002
1996	509	2140
1997	536	2308
1998	541	2497
1999	558	2621
2000	567	2771
2001	619	2833
2002	641	3170
2003	803	3282
2004	784	3463
2005	846	3366
2006	754	3387
2007	795	3609
2008	793	3798

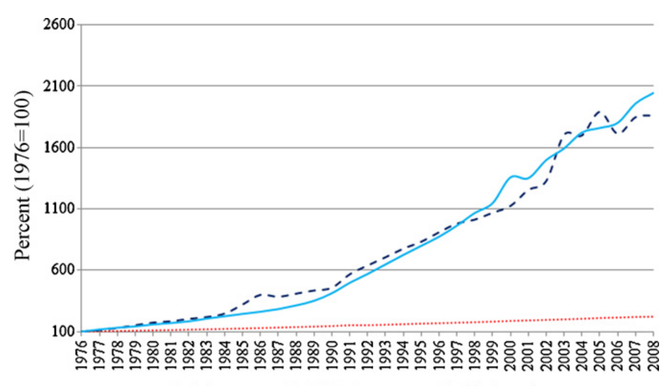

Fig. 3. . Per capita nominal capacity and per capita electricity consumption and population growth between 1976 and 2008.

3.2. Electricity generation statistics

3.2.1. Per capita nominal capacity

The per capita nominal capacity for each year is the total nominal capacities divided by the population in that particular year. The per capita nominal capacity in the year i can be calculated by the following equation:

$$PN_i = \frac{NC_i}{P_i} \tag{2}$$

3.2.2. Per capita electricity consumption

The per capita electricity consumption in the year i is electricity production minus electricity exchange with neighbouring countries, divided by population in particular year which can be

Table 9
Power plants electricity generation contribution (%) from 1976 to 2008.

Year	Conventional thermal (coal)	Conventional thermal (oil/gas)	Gas turbine	Combined cycle	Diesel engine	Hydro-power	Mini hydro	Biomass
1976	0.0	82.7	0.0	0.0	3.4	13.9	0.0	0.0
1977	0.0	85.9	0.0	0.0	2.8	11.2	0.0	0.0
1978	0.0	86.1	0.0	0.0	2.8	11.1	0.0	0.0
1979	0.0	80.4	3.4	0.0	3.9	12.3	0.0	0.0
1980	0.0	78.8	3.7	0.0	3.7	13.8	0.0	0.0
1981	0.0	77.4	3.0	0.0	3.4	16.2	0.0	0.0
1982	0.0	80.6	3.0	0.0	3.5	12.8	0.0	0.0
1983	0.0	79.1	3.3	0.0	3.7	13.9	0.0	0.0
1984	0.0	70.5	3.1	0.0	2.2	24.2	0.0	0.0
1985	0.0	58.9	6.2	8.7	2.5	23.8	0.0	0.0
1986	0.0	50.6	5.5	15.3	1.8	26.9	0.0	0.0
1987	0.0	55.3	1.9	17.1	0.6	25.1	0.0	0.0
1988	0.4	45.1	1.4	23.9	0.9	28.3	0.0	0.0
1989	11.0	40.6	0.3	19.8	0.5	27.9	0.0	0.0
1990	10.8	40.1	0.2	20.3	0.5	28.1	0.1	0.0
1991	13.8	36.7	3.1	21.1	0.6	24.6	0.1	0.0
1992	16.0	35.0	3.5	21.0	0.8	23.6	0.1	0.0
1993	17.9	32.9	5.9	20.0	1.3	21.9	0.2	0.0
1994	17.9	33.4	8.6	18.1	1.8	20.1	0.2	0.0
1995	18.7	31.8	10.5	17.5	1.9	19.4	0.2	0.0
1996	19.8	31.2	11.5	17.1	2.2	18.0	0.3	0.0
1997	20.0	30.7	12.7	17.3	2.6	16.5	0.3	0.0
1998	20.2	28.8	15.3	17.8	2.6	15.1	0.3	0.0
1999	21.0	26.3	17.1	18.9	2.8	13.7	0.2	0.0
2000	20.7	22.1	20.4	20.8	2.7	13.0	0.2	0.0
2001	21.8	15.2	22.4	25.0	2.8	12.6	0.2	0.0
2002	19.5	9.5	22.4	32.0	2.6	11.0	0.2	0.0
2003	18.7	6.6	23.0	39.0	2.3	10.3	0.2	0.0
2004	14.3	7.7	23.5	41.6	2.3	10.4	0.1	0.0
2005	19.4	4.3	23.5	40.5	1.9	10.3	0.1	0.0
2006	23.3	4.4	16.3	43.7	1.9	10.3	0.1	0.0
2007	28.3	3.9	16.1	40.3	1.8	9.4	0.1	0.0
2008	28.0	3.8	16.3	40.2	1.8	9.5	0.1	0.1

Table 10
Power plants nominal capacity contribution (%) from 1976 to 2008.

Year	Conventional thermal (coal)	Conventional thermal (oil/gas)	Gas turbine	Combined cycle	Diesel engine	Hydro-power	Mini hydro	Biomass
1976	0.0	72.0	0.0	0.0	5.7	22.4	0.0	0.0
1977	0.0	74.0	0.0	0.0	5.9	20.1	0.0	0.0
1978	0.0	64.0	6.6	0.0	6.2	23.2	0.0	0.0
1979	0.0	54.2	5.6	0.0	6.0	34.3	0.0	0.0
1980	0.0	59.3	4.9	0.0	5.8	30.1	0.0	0.0
1981	0.0	61.3	4.6	0.0	5.8	28.3	0.0	0.0
1982	0.0	65.0	4.2	0.0	5.2	25.6	0.0	0.0
1983	0.0	62.5	3.9	0.0	5.4	28.2	0.0	0.0
1984	0.0	55.5	8.9	0.0	6.5	29.1	0.0	0.0
1985	0.0	41.5	6.9	15.9	5.4	30.3	0.0	0.0
1986	0.0	44.4	5.9	19.1	4.0	26.5	0.0	0.0
1987	0.0	42.6	6.2	19.9	3.7	27.6	0.0	0.0
1988	6.2	40.0	5.8	18.6	3.5	25.9	0.0	0.0
1989	11.7	37.6	5.5	17.5	3.3	24.4	0.0	0.0
1990	3.0	38.7	9.0	20.4	2.8	25.9	0.1	0.0
1991	2.8	32.9	9.4	30.0	2.5	22.2	0.1	0.0
1992	3.3	32.2	11.8	29.5	2.2	20.9	0.1	0.0
1993	3.6	33.2	13.4	28.1	2.0	19.5	0.2	0.0
1994	4.8	26.5	16.7	31.4	1.9	18.5	0.2	0.0
1995	6.4	22.4	18.7	32.7	1.9	17.7	0.2	0.0
1996	6.8	19.6	20.6	34.0	2.0	16.7	0.2	0.0
1997	5.4	17.7	24.1	34.7	2.0	15.8	0.2	0.0
1998	4.9	15.4	24.1	36.9	2.2	16.2	0.2	0.0
1999	5.0	12.3	26.2	38.3	2.2	15.8	0.2	0.0
2000	10.8	10.0	28.9	34.1	2.7	13.2	0.3	0.0
2001	11.5	11.6	24.2	36.2	2.2	14.0	0.3	0.0
2002	10.8	10.0	28.9	34.1	2.7	13.2	0.3	0.0
2003	18.9	7.2	22.5	37.9	2.5	10.3	0.3	0.0
2004	23.4	41.7	7.7	14.0	2.5	10.5	0.3	0.0
2005	17.4	4.0	21.1	46.3	1.8	9.2	0.1	0.0
2006	22.6	4.5	16.5	43.8	2.1	10.3	0.1	0.0
2007	27.4	4.1	16.1	40.7	2.0	9.6	0.1	0.0
2008	27.2	4.1	16.6	40.3	2.0	9.5	0.1	0.2

Table 11
Total emission (ton) in Malaysian power plants from 1976 to 2008.

Year	SO_2	NO_x	CO	CO_2
1976	73,088.4	11,141.5	891.3	3,788,117.1
1977	88,100.2	13,429.9	1074.3	4,566,167.8
1978	98,782.8	15,058.7	1204.7	5,119,841.0
1979	101,834.9	15,730.7	1366.1	5,404,772.9
1980	110,611.2	17,111.7	1498.9	5,886,054.8
1981	116,530.3	17,977.4	1549.2	6,170,433.3
1982	131,350.0	20,260.4	1744.2	6,953,130.0
1983	144,491.4	22,317.9	1937.0	7,667,424.5
1984	138,667.2	21,432.5	1867.4	7,367,086.5
1985	127,975.3	21,052.6	2486.5	7,577,811.2
1986	117,354.5	20,199.1	2815.9	7,495,729.5
1987	135,855.0	22,995.7	3027.4	8,440,173.3
1988	125,206.7	22,675.2	3548.2	8,583,119.7
1989	151,645.4	32,275.9	3709.0	10,614,200.5
1990	176,058.7	37,526.6	4376.6	12,386,029.0
1991	209,921.7	48,062.9	5740.8	15,647,490.0
1992	240,668.2	57,116.9	6644.7	18,273,649.1
1993	275,078.3	67,498.5	7814.7	21,372,155.0
1994	306,998.1	75,653.3	8885.9	24,026,795.0
1995	341,850.8	85,443.3	10,105.7	27,089,955.0
1996	378,082.9	95,777.0	11,267.9	30,213,345.0
1997	402,632.9	104,434.8	12,590.4	32,983,639.5
1998	448,136.3	117,620.1	14,818.9	37,538,975.0
1999	467,037.4	127,147.6	16,621.5	40,692,085.0
2000	457,490.7	234,520.6	72,668.1	99,660,925.3
2001	584,851.1	274,845.6	76,347.1	110,886,791.9
2002	832,721.0	337,254.7	82,567.2	129,724,569.9
2003	847,656.3	380,631.4	74,364.7	129,729,776.7
2004	1,023,525.7	447,800.2	74,922.3	143,305,988.6
2005	1,075,337.8	478,564.2	85,220.6	156,810,558.0
2006	1,186,042.3	512,739.7	87,389.8	165,637,190.4
2007	1,379,559.2	597,613.6	90,713.5	184,252,949.1
2008	1,471,655.8	644,339.4	99,230.7	199,450,709.5

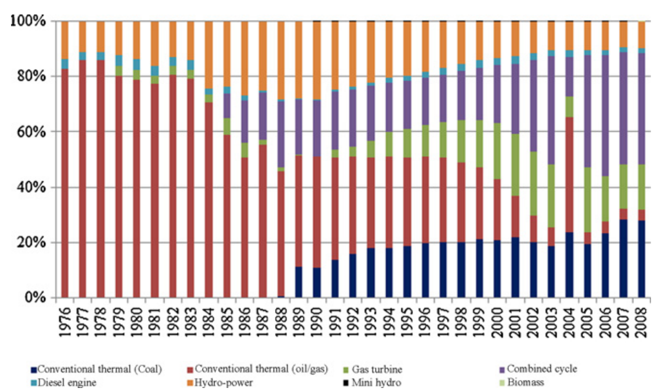

Fig. 4. Pattern of electricity generation for each type of power plants from 1976 to 2008.

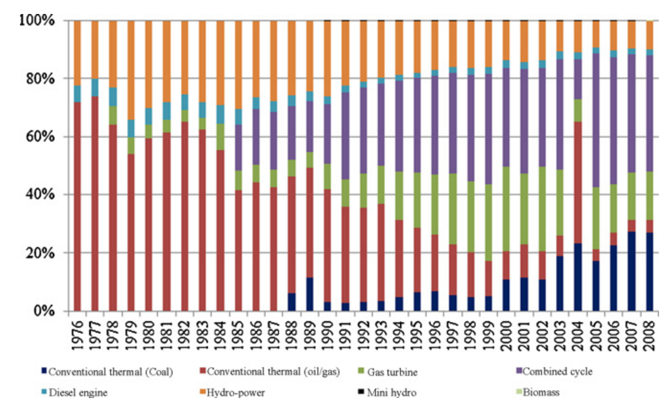

Fig. 5. Pattern of nominal capacity for each type of power plants from 1976 to 2008.

calculated by the following equation:

$$PC_i = \frac{EG_i - EX_i}{P_i} \quad (3)$$

3.2.3. Percentage of electricity generation and nominal capacity

To understand the changes in pattern of electricity generation and nominal capacity, the share of each type of power plants should be identified by the following equation:

$$PE_i^n = \frac{EG_i^n}{EG_i} \times 100 \quad (4)$$

$$NP_i^n = \frac{NC_i^n}{NC_i} \times 100 \quad (5)$$

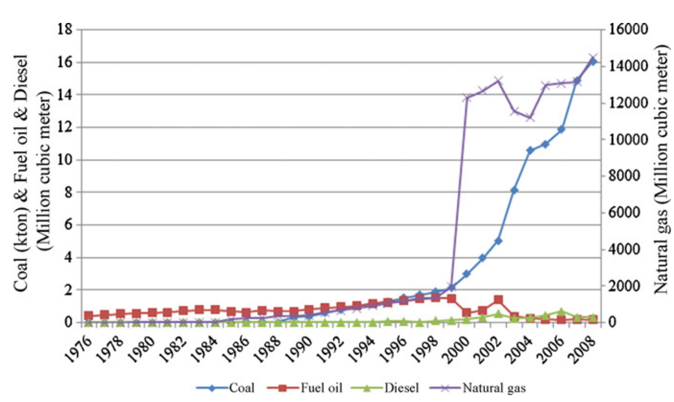

Fig. 6. Total fuel consumed in Malaysian power plants from 1976 to 2008.

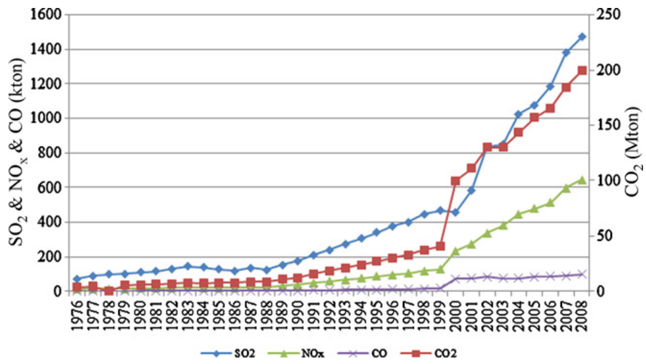

Fig. 7. Total emission in Malaysian power plants from 1976 to 2008.

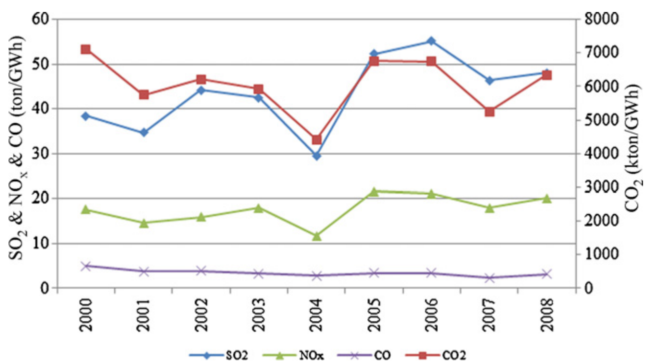

Fig. 8. Emission per unit electricity generation from 2000 to 2008.

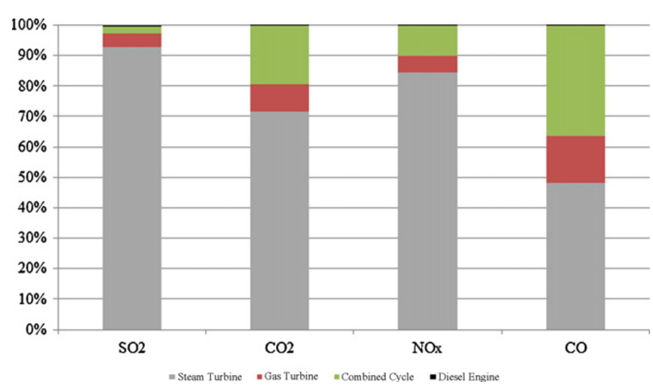

Fig. 9. Power plants emission contribution in 2008.

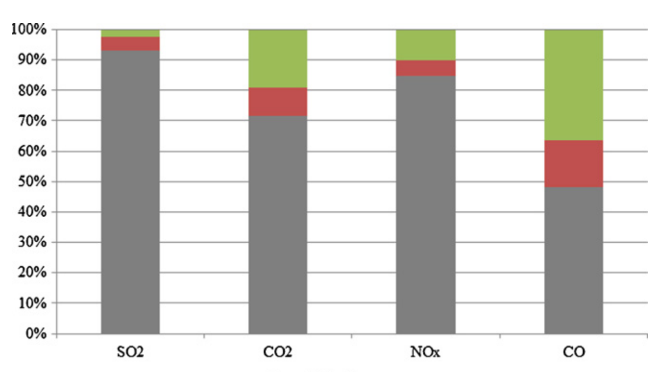

Fig. 10. Comparison between thermal power plants with regard to emission.

3.3. Emissions

Using emission factors is not necessarily the best way to estimate emissions; however, given the lack of any continuous emissions measurements or frequent stack measurements, it is the only feasible option [69–71].

The data on CO_2, SO_2, NO_x and CO emissions from fossil fuel for a unit of electricity generation are determined. These data are collected from Refs. [69–71]. All the survey emission data are tabulated in Table 10, and these are based on emission factors for each fuel type and applied to the following four types of power plants: steam turbine, gas turbine, combined cycle and diesel engine.

As mentioned in Table 1, two kinds of power plants, steam turbine and gas turbine, use more than one type of fossil fuel. This means that the emission factor of a fuel will be different based on the power plant type. Also as electricity generation by biomass fuel is very low and has been used since 2008, its emission production is negligible.

3.4. Emission production

Emission production is equal to emission factor multiplied by the amount of fuel consumed. Therefore, the emission p due to use fuel f in power plant type n in the year i, can be calculated by the following equation:

$$\mathrm{EM}_{if}^{\mathrm{np}} = \mathrm{EF}_{\mathrm{f}}^{\mathrm{pn}} \times \mathrm{FC}_{if}^{\mathrm{n}} \tag{6}$$

To assess the impact of each type of fuel in total emission of each power plant, contribution of each fuel in total emission should be calculated by the following equation:

$$\mathrm{FE}_{if}^{\mathrm{np}} = \frac{\mathrm{EM}_{if}^{\mathrm{np}}}{\Sigma_{\mathrm{f}}\mathrm{EM}_{if}^{\mathrm{np}}} \times 100 \tag{7}$$

The annual emission is the summation of emission for all types of power plants by all types of fuel used. This can be calculated by the following equation:

$$\mathrm{EM}_{i}^{\mathrm{p}} = \Sigma_{\mathrm{n}}\Sigma_{\mathrm{f}}\mathrm{EM}_{if}^{\mathrm{np}} \tag{8}$$

Thermal energy released due to inflammation of each type of fuel depends on fuel's calorific values. The share of each type of fuel in total thermal energy consumed in power plants can be calculated by the following equation:

$$\mathrm{PF}_{if}^{\mathrm{n}} = \frac{\mathrm{CV}_{\mathrm{f}} \times \mathrm{FC}_{if}^{\mathrm{n}}}{\Sigma_{\mathrm{f}}\mathrm{CV}_{\mathrm{f}} \times \mathrm{FC}_{if}^{\mathrm{n}}} \times 100 \tag{9}$$

3.5. Emission per unit electricity generation

The emission per unit electricity generation for each year is a function of annual emission divided by total electricity generated by power plants. This can be calculated by the following equation:

$$\mathrm{EP}_{i}^{\mathrm{p}} = \frac{\mathrm{EM}_{i}^{\mathrm{p}}}{\mathrm{EG}_{i}^{\mathrm{t}}} \tag{10}$$

3.6. Emission per unit electricity generation for each type of power plant

The emission per unit electricity generation for each type of power plant is a function of the emission factor, fuel consumption in each type of power plant and electricity generation from that particular power plant. The emission p per unit electricity genera-

Table 12
Emission per unit of electricity generation (kg/GWh) from 2000 to 2008.

Year	SO_2	NO_x	CO	CO_2
2000	38,386.6	17,563.7	4893.6	7,118,625
2001	34,655.3	14,585.9	3785.5	5,750,680
2002	44,195.3	15,940.1	3878.4	6,212,607
2003	42,551.6	17,892.2	3198.1	5,920,705
2004	29,481.6	11,687.5	2732.9	4,407,696
2005	52,238.2	21,520.9	3363.9	6,764,449
2006	55,140.2	21,020.9	3352.8	6,745,155
2007	46,345.9	17,954.7	2241.5	5,257,357
2008	48,062.6	20,122.5	3189.4	6,343,360

Table 13
Total emission (ton) in thermal power plants from 2000 to 2008.

Year	Emission	Steam turbine	Gas turbine	Combined cycle	Diesel engine	Total
2000	SO_2	389,135.59	46,563.33	17,644.91	4146.82	457,490.66
	CO_2	62,901,347.50	17,841,044.38	18,703,606.60	214,926.80	99,660,925.27
	NO_x	168,817.51	32,310.15	31,760.74	632.14	233,520.64
	CO	39,288.73	15,683.89	17,644.91	50.57	72,668.11
2001	SO_2	495,552.28	62,940.36	20,124.61	6233.82	584,851.08
	CO_2	70,530,378.48	18,701,228.29	21,332,090.66	323,094.52	110,886,791.96
	NO_x	202,845.81	34,825.23	36,224.30	950.28	274,845.62
	CO	40,251.68	15,894.76	20,124.61	76.02	76,347.08
2002	SO_2	704,153.24	8,832.97	22,992.80	10,236.57	746,215.58
	CO_2	84,174,581.52	20,647,063.71	24,372,370.77	530,553.94	129,729,776.69
	NO_x	254,107.51	40,199.75	41,387.04	1560.45	380,631.48
	CO	42,898.38	16,551.14	22,992.80	124.84	82,567.16
2003	SO_2	754,942.33	60,076.84	28,298.37	4338.80621	847,656.34
	CO_2	79,569,750.99	19,938,879.12	29,996,269.43	224,877,151.36	129,729,777
	NO_x	292,379.17	36,653.84	50,937.06	661.40	380,631
	CO	28,795.49	17,217.90	28,298.37	52.91	74,364.67
2004	SO_2	957,268.56	44,515.02	10,064.19	11,677.98	1,023,525.75
	CO_2	124,262,041.29	7,770,640.75	10,668,045.54	605,260.99	143,305,988.58
	NO_x	412,190.27	15,714.26	18,115.55	1780.18	447,800.25
	CO	58,819.77	5895.96	10,064.19	142.41	74,922.33
2005	SO_2	948,371.52	88,549.71	32,795.86	5620.77	1,075,337.85
	CO_2	97,980,983.13	23,774,647.25	34,763,607.41	291,320.23	156,810,558.03
	NO_x	373,823.91	44,851.01	59,032.54	856.82	478,564.29
	CO	32,478.74	19,877.50	32,795.86	68.54	85,220.64
2006	SO_2	1,018,846.81	119,141.40	35,719.46	12,334.63	1,186,042.30
	CO_2	107,582,114.64	19,607,150.48	37,862,630.51	639,294.74	165,637,190.37
	NO_x	406,451.69	40,112.71	64,295.03	1880.28	512,739.72
	CO	36,906.18	14,613.74	35,719.46	150.42	87,389.81
2007	SO_2	1,275,149.72	65,725.84	32,800.45	5883.20	1,379,559.21
	CO_2	132,562,052.24	16,617,494.01	34,768,481.01	304,921.84	184,252,949.10
	NO_x	506,067.32	31,608.66	59,040.82	896.83	597,613.63
	CO	44,095.70	13,745.63	32,800.45	71.75	90,713.53
2008	SO_2	1,365,550.64	64,461.39	36,143.68	5500.06	1,147,655.77
	CO_2	142,737,343.57	18,116,003.22	38,312,298.59	285,064.18	199,450,709.55
	NO_x	544,470.51	33,971.88	65,058.62	838.42	644,339.44
	CO	47,757.33	15,262.66	36,143.68	67.07	99,230.75

tion in a power plant type n in the year i, can be calculated by the following equation:

$$\mathrm{EP}_i^{\mathrm{n\,p}} = \frac{\Sigma_{\mathrm{f}} EF_{\mathrm{f}}^{\mathrm{n\,p}} \times FC_{i\mathrm{f}}^{\mathrm{n}}}{\mathrm{EG}_i^{\mathrm{n}}} \tag{11}$$

To estimate each type of emission for a unit electricity production in each type of power plants used, only the values related to certain years are applied. The average emission for certain years considered as a selected value, calculated by the following equation:

$$\mathrm{EP}^{\mathrm{n\,p}} = \frac{\mathrm{EP}_{2000}^{\mathrm{n}}\mathrm{p} + \mathrm{EP}_{2001}^{\mathrm{n}}\mathrm{p} + \cdots + \mathrm{EP}_{2008}^{\mathrm{n}}\mathrm{p}}{9} \tag{12}$$

4. Results and discussion

4.1. Electricity growth

The nominal capacity and electricity production growth by type of power plant in Malaysia is shown in Figs. 1 and 2. The Annual electricity production growth in the country was 9.96% and the annual nominal capacity growth was 9.89%. This is equivalent to the annual growth of 3144.65 GWh of electricity production that needs to create 650 MW of new power generation capacity annually.

4.2. Per capita capacities

The annual population growth is estimated using the data in Table 5 and Eq. (1). The nominal capacity and electricity consumption per person have been calculated using Eqs. (2) and (3), based on the data in Tables 2–4. From 1976 to 2008, net exchange of

Table 14
Emission per unit electricity generation (kg/GWh) in thermal power plants from 2000 to 2008.

Year	Emission	Steam turbine	Gas turbine	Combined turbine	Diesel engine
2000	SO_2	31,868.15	3593.71	435.24	2489.54
	CO_2	5,151,288.00	1,376,953.16	461,352.68	129,030.92
	NO_x	13,907.16	2493.66	783.43	379.50
	CO	3217.54	1210.47	435.24	30.36
2001	SO_2	26,059.75	4471.78	495.22	3628.54
	CO_2	3,709,001.81	1,328,684.07	524,929.64	188,064.33
	NO_x	10,667.11	2474.26	891.39	553.13
	CO	2116.73	1129.29	495.22	44.25
2002	SO_2	28,571.85	7547.37	738.01	7338.04
	CO_2	3,415,483.12	1,634,504.73	782,294.04	380,325.41
	NO_x	10,310.71	3182.37	1328.42	1118.60
	CO	1740.65	1310.25	738.01	89.49
2003	SO_2	36,211.74	3169.78	880.53	2289.61
	CO_2	3,816,661.12	1,052,017.05	933,358.31	118,668.68
	NO_x	14,024.33	1933.93	1584.95	349.03
	CO	1381.21	908.45	880.53	27.92
2004	SO_2	16,503.78	6488.60	789.91	5699.35
	CO_2	2,142,338.18	1,132,663.91	837,300.49	295,393.36
	NO_x	7106.36	2290.54	1421.83	868.80
	CO	1014.08	859.41	789.91	69.50
2005	SO_2	43,959.21	4139.42	889.60	3249.94
	CO_2	4,541,644.45	1,111,390.68	942,972.05	168,441.88
	NO_x	17,327.60	2096.65	1601.27	495.42
	CO	1505.46	929.21	889.60	39.63
2006	SO_2	39,457.49	7841.09	876.85	6964.78
	CO_2	4,164,305.50	1,290,411.04	929,459.07	360,979.53
	NO_x	15,740.90	2639.95	1578.33	1061.70
	CO	1429.29	961.78	876.85	84.94
2007	SO_2	39,083.13	4028.97	8.03	3225.79
	CO_2	4,063,005.41	1,018,646.99	8514.60	167,190.39
	NO_x	15,510.88	1,937.60	14.46	491.74
	CO	1351.53	842.60	8.03	39.34
2008	SO_2	40,587.03	3737.78	849.78	2888.01
	CO_2	4,242,453.37	1,050,452.76	900,770.67	149,683.20
	NO_x	16,182.81	1969.85	1529.61	440.24
	CO	1419.45	885.00	849.78	35.22

Table 15
Emission per unit electricity generation (kg/GWh) in thermal power plants.

Emission	Steam turbine	Gas turbine	Combined cycle	Diesel engine
SO_2	33,589.1	5002.1	662.6	4197.1
CO_2	3,916,242.3	1,221,747.1	702,327.9	217,530.9
NO_x	13,419.8	2335.4	1192.6	639.8
CO	1686.2	1004.0	662.6	51.2

electricity in Malaysia is a positive number and it shows the country's electricity generation is higher than its demand. Therefore, the per capita rate of electricity generation and consumption has been affected along these years. The results are tabulated in Table 8 and illustrated in Fig. 3.

For 33 years, from 1976 to 2008, average of population growth in Malaysia was 2.5%. Per capita electricity consumption increased from 413 kWh in 1976 to 3798 kWh in 2008.

4.3. Pattern of electricity generation

The pattern of electricity generation and nominal capacity, based on the power plant type is calculated based on the data in Tables 2 and 3 and Eqs. (4) and (5). The results are tabulated in Tables 9 and 10, and illustrated in Figs. 4 and 5.

Fig. 4 shows that the electricity generation from fossil fuels is much higher than renewable resources. This is due to the tendency to use more fossil fuel power plants in order to meet high electricity demand. There is a slight increase to justify the application conventional thermal (coal) power plants while the diesel engine power plants are being slowly phase out. Generally, from 2000 to 2005 the usage of combined cycles has increased, and from 2005 this trend has been levelling out.

4.4. Emission production

Based on Table 6, the quantity of all types of fuel consumed in power plants in Malaysia is illustrated in Fig. 6. The growth of all types of fuel consumed by Malaysian power plants is depicted in the figure. Although natural gas is expected to be the fastest growing component of world energy consumption [74], it only grew 40.6% in Malaysia from 1976 to 2008, whereas by comparison, coal grew to 97.8% in the same period Moreover, in this period, the annual average growth for diesel and fuel oil was 27.7% and 1.7% respectively. The total emission in Malaysian power plants was calculated based on Eq. (8) and Tables 6 and 7. The total emission in Malaysian thermal power plants from 1976 to 2008 are presented in Table 11 and illustrated in Fig. 7.

For the past 33 years, the average annual growth rate of emission was 14.81% for CO_2, 10.32% for SO_2, 14.38% NO_x and 21.52% for CO. As seen in Fig. 7, increases in CO_2, SO_2 and NO_x emission observed were due to the increase in the coal and natural gas consumption.

Based on Table 1, most of the thermal power plants use both coal and natural gas as fuel. The year 2008 is considered as a sample to show that the highest emissions in power plants are due to the use of coal. 56% of total emission in this year was due to use of coal alone. If the use of coal in thermal power plants can be avoided, the

amount of CO_2, SO_2 and CO emitted from these power plants will significantly decrease.

The emission per unit electricity generation is calculated using Eq. (10) and the results are tabulated in Table 12 and shown in Fig. 8. The important point from this result is the trend of emission per unit electricity generation is decreasing. This is due to more natural gas being used instead of liquid fuels and the increasing efficiency of thermal power plants.

Between 1976 and 2008, there was detailed information of fuel consumed and electricity generated for all types of power plants. Therefore, the amount of total emission and emission per unit of electricity generation in each type of power plants were more precisely determined. These data are calculated using Eqs. (8) and (11) and tabulated in Tables 13 and 14.

The emission per unit electricity generation for each type of power plants in Malaysia was calculated using Eq. (12), based on the data in Table 14 and the result is tabulated in Table 15.

The data of this table has been calculated by using nine years fuel mix data. Therefore, by changing the fuel mix used in thermal power plants, this data will be affected. For example, by increasing the contribution of natural gas in power plants, the emission per unit electricity generation will decrease.

The data for year 2008 in Table 14 is selected to show the share of each type of power plant for total emission. The contributions of each type of thermal power plants in total emission in 2008 are presented in Fig. 9.

The figure shows that the contribution of diesel engines for all types of emission were insignificant. Fig. 10 shows the comparison of each type of emission in all thermal power plants in Malaysia except the diesel engine that was eliminated due to its insignificance share in the total emission. Comparing the thermal power plants regards to the emission show that, the worst type is steam turbine that produces the highest amount of emission while the best type is the gas turbine. SO_2 emission of combined cycle was less than gas turbine in this year.

5. Conclusion

This study describes the pattern of electricity generation and emission in Malaysia for the past 33 years since 1976–2008. It shows thermal power generators that uses fossil fuels plays an important role in Malaysian electricity generation and these are also an important source of emissions in the country. The data shows that the best type of thermal power plants with regard to air pollution is gas turbine, combined cycle and steam turbine, respectively. The data has been calculated based on the past fuel mix used in the power plants. Therefore, by altering the fuel mix, a different scenario of emission will be seen. For example, by replacing coal types with natural gas, the amount of emissions per unit of electricity generation will decrease significantly. The hydro-power plants are the cleanest energy source, since it has no emission. However, the study shows that these plants are unstable and can only be used as a supplementary power source unreliability of water resources. Malaysia has many potential for generating electricity from non-hydro renewable energy resources such as biomass and solar. The development of these resources provides a more diverse energy resource besides the dominant fossil fuels. In addition, it helps to meet the growing energy demand and addresses the environmental concerns and sustainability issues. However, the amount of electricity generated from these resources is still under 10%. Therefore, based on the data analyses, Malaysia has to cover the required new capacities by constructing new thermal power plants. Using more thermal power plants will cause an increase of emission in the future. On the positive side, it is also possible to achieve significant emission reductions with gradual conversion of liquid fuel to natural gas and increasing the contribution of the combined cycle as a more efficient type of thermal power plants.

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